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(54) FIBER REINFORCED PLASTIC PROPELLER SHAFT

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(57) **ABSTRACT**

A fiber reinforced plastic propeller shaft has a fiber reinforced plastic pipe, and at least one metal member attached to an end of the pipe. The metal member is provided with a serration having a plurality of teeth having an apex angle. When the metal member is attached to the end of the pipe, each tooth forms on the inner surface of the pipe end a groove extending along the axial direction of the pipe. The apex angle of each tooth is between 45° and 75°.

Fig. 1

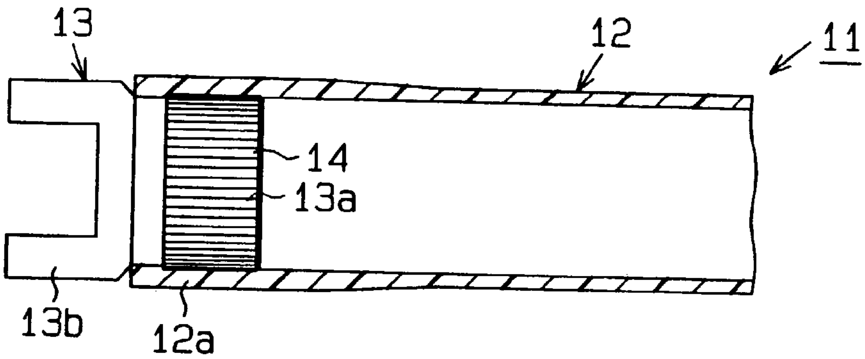


Fig. 2

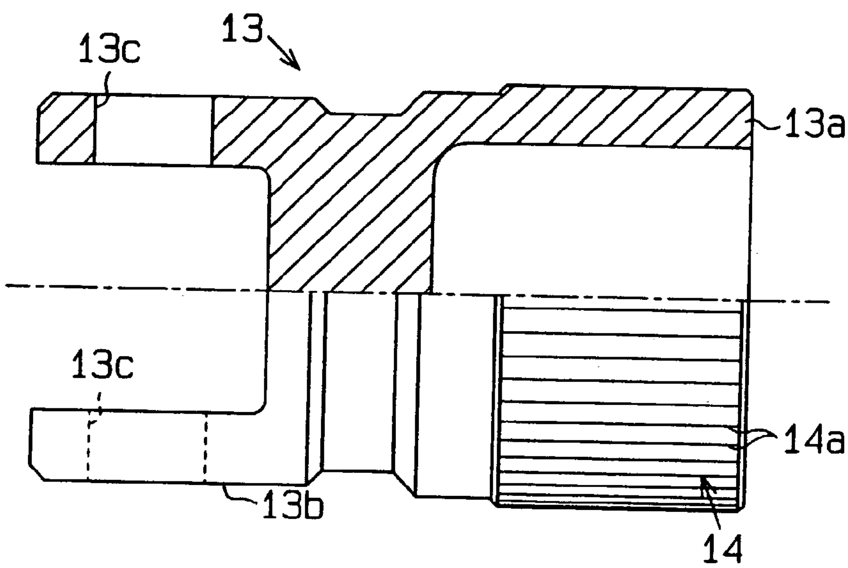


Fig.3(a)

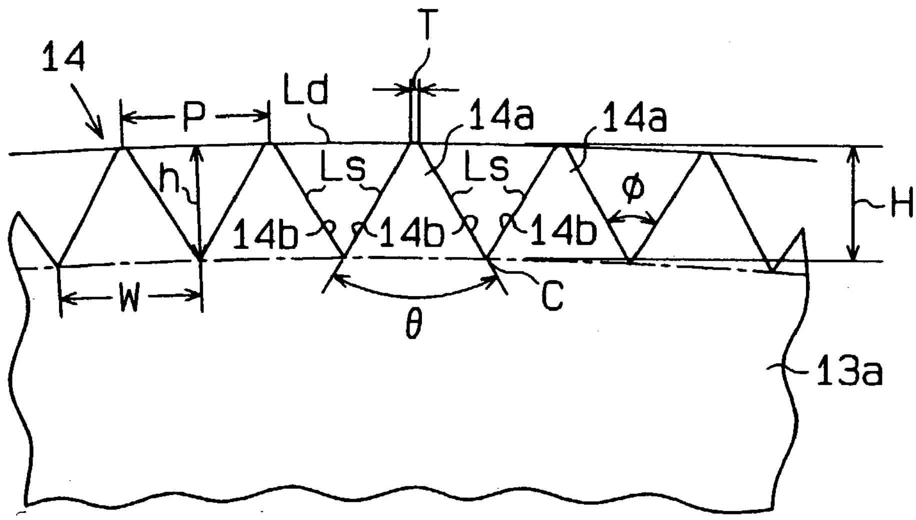

14
P
Ld
T
14a
14a
h
Ls
Ls
φ
H
14b
14b
14b
W
θ
C
13a

Fig.3(b)

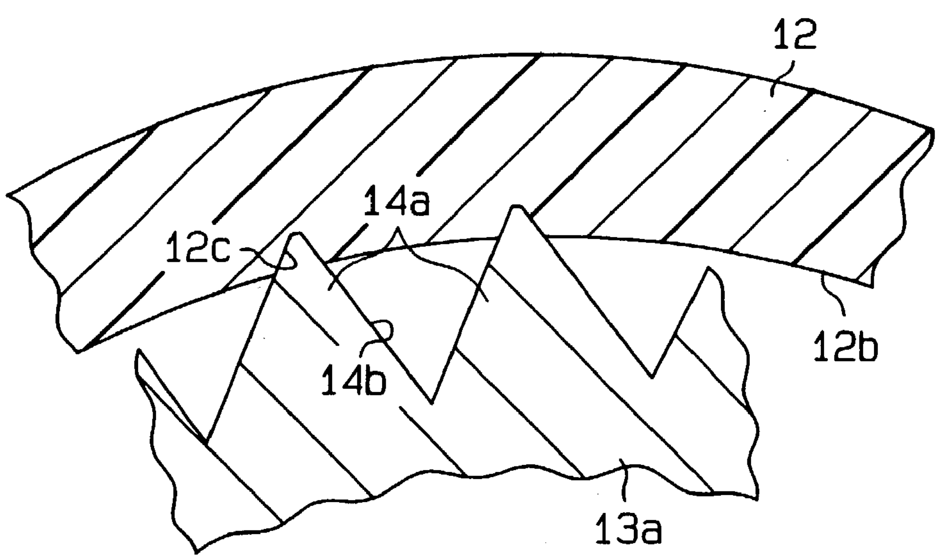

12
14a
12c
14b
12b
13a

Fig.4

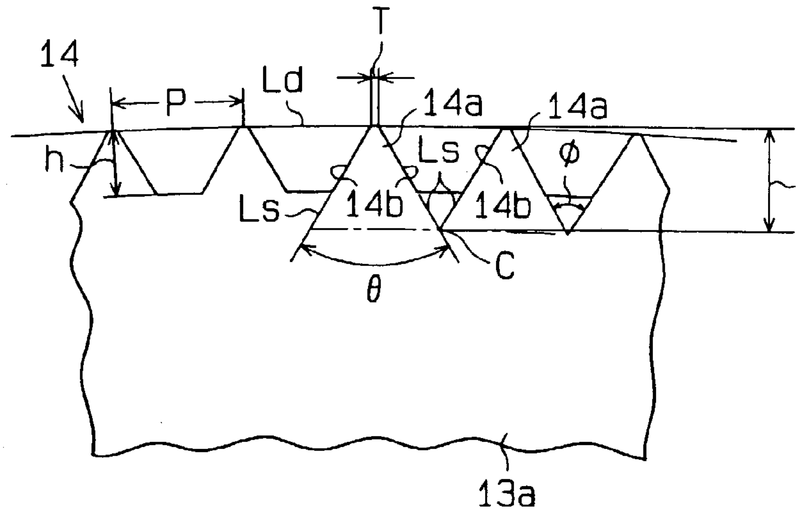


Fig.5(a)(Prior Art)

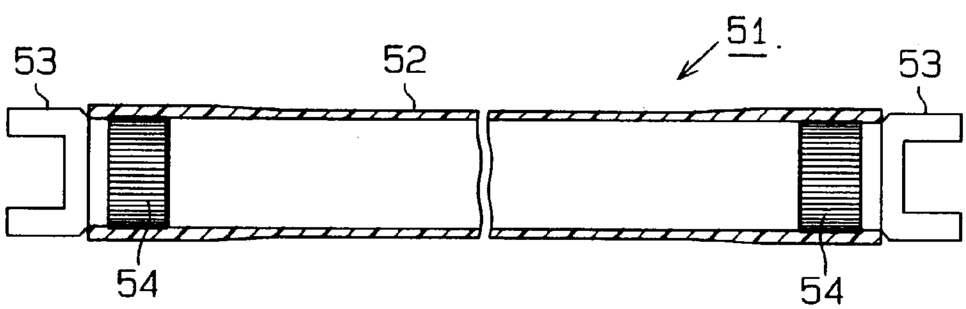
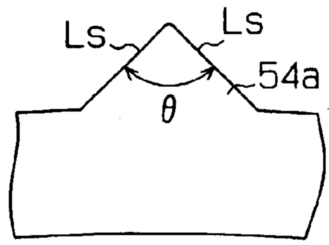


Fig.5(b)(Prior Art)



FIBER REINFORCED PLASTIC PROPELLER SHAFT

BACKGROUND OF THE INVENTION

[**0001**] The present invention relates to a fiber reinforced plastic propeller shaft that includes a fiber reinforced plastic pipe and metal members attached to the ends of the pipe, each metal member having serration including a number of teeth that form grooves extending in the axial direction in the inner surface of the ends of the pipe.

[**0002**] A propeller shaft for transmitting power generated by the engine of an automobile to driven wheels typically includes a metal shaft and yokes welded to the ends of the shaft. The yokes form part of metal universal joints. The universal joints are coupled to a drive shaft and a driven shaft, respectively. This type of propeller shaft is referred to as a metal propeller shaft.

[**0003**] In recent years, there is a great demand for lighter parts of vehicles to reduce the weight of vehicles. Accordingly, propeller shafts made of fiber-reinforced plastic (FRP) are used to reduce the weight. **FIG. 5**(*a*) shows such a fiber reinforced plastic (FRP) propeller shaft **51**, which is disclosed, for example, in Japanese Laid-Open Patent Publication No. 2000-120649. The propeller shaft **51** has an FRP pipe **52** and metal yokes **53** press fitted to the ends of the pipe **52**. The yokes **53** couple the pipe **52** to a drive shaft and driven shaft (neither is shown).

[**0004**] Each yoke **53** has a serration **54** formed on a part of the outer surface that contacts the FRP pipe **52**. The outer diameter of the serration **54** is greater than the inner diameter of the FRP pipe **52**. Press fitting the contacting part of the yoke **53** into the FRP pipe **52** causes the teeth of the serration **54** of the yoke **53** to form grooves on the inner surface of the FRP pipe **52**. The engagement of the serration **54** and the FRP pipe **52** ensures a sufficient coupling strength to permit the yoke **53** and the FRP pipe **52** to rotate integrally.

[**0005**] The apex angle θ of each tooth **54***a* of the serration **54** is approximately 90°. As shown in **FIG. 5**(*b*), the apex angle θ refers to an angle defined by lines Ls representing the sides of the tooth **54***a*. A greater apex angle θ requires a greater force to press fit the serration **54** into the FRP pipe **52**. This requires facilities of a greater press force and may break the pipe **52**. The cost is increased accordingly. Further, since it is difficult to point the end of the tooth **54***a*, the end of the tooth **54***a* is formed to have a trapezoidal or arcuate cross-section. Therefore, an apex angle of approximately 90° is likely to cause the teeth **54***a* to expand the FRP pipe **52** when the serration **54** is press fitted. In this case, the teeth **54***a* cannot form grooves having a sufficient depth, and the engagement of the teeth **54***a* with the inner surface of the FRP pipe **52** is not sufficient. As a result, the coupling strength of the FRP pipe **52** and the yokes **53** is not satisfactory.

[**0006**] The engagement portions of the yokes coupled to an FRP pipe must transmit a required torque (torsional torque) and prevent the FRP pipe from receiving excessive force when the yokes are press fitted to the pipe. Therefore, the press fitting force needs to be minimized. However, the torque transmitting capability from the yokes to the FRP pipe does not depend only on the engagement amount of the teeth **54***a* with the FRP pipe **52**, but also on the reactive force, or fastening force, produced when the serration **54** is press fitted to the pipe **52** and expands the pipe **52**. Thus, if the apex angle θ is too small, the pipe **52** will not be sufficiently expanded and there will be no sufficient fastening force. As a result, a sufficient torque transmitting capability will not be obtained. Also, if the apex angle θ is too small, a required strength will not be obtained.

[**0007**] In recent car designs, a technology to make a propeller shaft to collapse or break in the axial direction for gradually absorbing the great impact of a collision has been proposed. This technology prevents an excessive impact in a collision and thus creates a sufficient time for various safety devices such as air bags to operate. In one of the designs according to the technology, the yokes are pressed further into an FRP pipe than the original positions by the impact force of a collision when the impact force exceeds a predetermined value. This axially collapses or breaks the propeller shaft. In this configuration also, the yokes are preferably press fitted to the FRP pipe with a relatively small force during manufacture.

SUMMARY OF THE INVENTION

[**0008**] Accordingly, it is an objective of the present invention to provide an FRP propeller shaft that permits serrations to be easily press fitted to an FRP pipe and sufficient torsional torque to be transmitted between the FRP pipe and the serrations.

[**0009**] To achieve the foregoing and other objectives and in accordance with the purpose of the present invention, a fiber reinforced plastic propeller shaft is provided. The shaft has a fiber reinforced plastic pipe, and a metal member attached to at least one end of the pipe. The metal member is provided with a serration having a plurality of teeth having an apex angle. When the metal member is attached to the end of the pipe, each tooth forms on the inner surface of the pipe end a groove extending along the axial direction of the pipe. The apex angle of each tooth is between 45° and 75°.

[**0010**] Other aspects and advantages of the invention will become apparent from the following description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[**0011**] The invention, together with objects and advantages thereof, may best be understood by reference to the following description of the presently preferred embodiments together with the accompanying drawings in which:

[**0012**] **FIG. 1** is a partial cross-sectional view illustrating an FRP propeller shaft according to one embodiment of the present invention;

[**0013**] **FIG. 2** is a partly cross-sectional view illustrating the yoke of **FIG. 1**;

[**0014**] **FIG. 3**(*a*) is an enlarged partial front view of the serration of the yoke shown in **FIG. 2**;

[**0015**] **FIG. 3**(*b*) is an enlarged partial cross-sectional view showing the engaging portion of the serration and the FRP pipe;

[**0016**] **FIG. 4** is an enlarged partial front view showing a serration according to another embodiment;

[0017] **FIG. 5**(*a*) is a cross-sectional view showing a prior art FRP propeller shaft; and

[0018] **FIG. 5**(*b*) is a schematic view showing the apex angle of a tooth of the serration shown in **FIG. 5**(*a*).

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0019] One embodiment according to the present invention will now be described with reference to FIGS. **1** to **3**. **FIG. 1** is a cross-sectional view showing an FRP propeller shaft **11**. **FIG. 2** is a side view of a yoke **13** with a half cut away. **FIG. 3**(*a*) is an enlarged partial front view showing a serration **14**. **FIG. 3**(*b*) is an enlarged partial cross-sectional view showing the engaging portions **13***a* of the serration **14** and an FRP pipe **12**.

[0020] As shown in **FIG. 1**, the FRP propeller shaft **11** includes the FRP pipe **12** and a pair of metal members, which are the metal yokes **13** in this embodiment. Each yoke **13** is press fitted into one end of the pipe **12**. Each yoke **13** includes an engaging portion **13***a* and a joint portion **13***b*. The engaging portion **13***a* is press fitted in the corresponding end of the FRP pipe **12**. The joint portion **13***b* is coupled to a universal joint (for example, a cross joint), which is used to couple the propeller shaft **11** with the drive shaft of the vehicle. A hole **13***c* is formed in the joint portion **13***b* (see **FIG. 2**). The universal joint is engaged with the hole **13***c*. The engaging portion **13***a* of each yoke **13** is press fitted to an engaging portion **12***a* located at each end of the FRP pipe **12**. The yokes **13** are thus coupled to the FRP pipe **12**.

[0021] The engaging portions **12***a* of the FRP pipe **12** are thicker than the remainder of the pipe **12**. The FRP pipe **12** is manufactured through the filament winding method (FW method). The reinforcing fibers of the pipe **12** are carbon fibers. The matrix resin is epoxy resin. Fibers are impregnated with resin and are wound about a mandrel. Then, the resin is hardened with heat. Thereafter, the mandrel is removed to form the FRP pipe **12**.

[0022] The serration **14** having axially extending teeth **14***a* is formed on the outer surface of each engaging portion **13***a*. The teeth **14***a* form axially extending grooves **12***c* (see **FIG. 3**(*b*)) on the end inner surface **12***b* of the FRP pipe **12**. As shown in **FIG. 3**(*a*), the teeth **14***a* are formed at a predetermined pitch P along the circumferential direction. Each tooth **14***a* has a triangular cross-section.

[0023] The apex angle θ of each tooth **14***a* is 60°. The connecting angle ϕ defined by any adjacent pair of the teeth **14***a* is substantially equal to the apex angle θ. Specifically, the difference between the apex angle θ and the connecting angle ϕ is from 0° to 5°. In this embodiment, the cross-section of the teeth **14***a* form a saw-tooth pattern.

[0024] The outer diameter of each serration **14** is between 70 mm and 75 mm (in this embodiment, 71 mm). A predetermined number of teeth, which is between 142 and 145 (i.e., 142, 143, 144, or 145), are formed on the serration **14**. In this embodiment, the number of the teeth is **144**. The sides of each tooth **14***a* are represented by lines Ls in **FIG. 3**(*a*). The distance H between the intersection of lines Ls of adjacent teeth **14***a* and the outer circumferential diameter line Ld of the serration **14** is between 0.9 mm and 1.8 mm. In this embodiment, the distance H is 1.25 mm. In this embodiment, the tooth height h is equal to the distance H.

[0025] The distal tooth thickness T of the teeth **14***a* is equal to or less than 0.1 mm and the width W of the proximal end of the teeth **14***a* is 1.5 mm. In this embodiment, the distal tooth thickness T is 0.05 mm. The radial dimension of the portion of each tooth **14***a* that engages with, or digs into, the FRP pipe **12** is equal to or less than one fifth of the tooth height h. In this embodiment, the radial dimension of the digging portion is 0.15 mm. For purposes of illustration, the digging portions are exaggerated in **FIG. 3**(*b*).

[0026] The serration **14** of each yoke **13** is formed, for example, with a topping hob. Unlike a normal hob, the topping hob can machine the distal section of the teeth **14***a* to make the distal end narrow.

[0027] The operations of the yoke **13**, which is constructed as above, will hereafter be described. When coupling the yokes **13** with the FRP pipe **12**, the FRP pipe **12** is fixed with a jig. The pipe **12** and the yoke **13** are aligned and the serration **14** is press fitted in the pipe **12** with a tool. When the serration **14** is press fitted, the teeth **14***a* enter the pipe **12** while forming the grooves **12***c* on the inner surface of the pipe **12**. The teeth **14***a* are firmly engaged with the grooves **12***c*, which engages the yoke **13** with the pipe **12** at a high strength. When the yokes **13** are attached to the ends of the FRP pipe **12**, the manufacture of the propeller shaft **11** is completed.

[0028] If the apex angle θ of the serration teeth **14***a* is approximately 90° as in the prior art, a great force is required to press fit the serration **14** into the FRP pipe **12**. However, in the above embodiment, the apex angle θ is 60° and the connecting angle ϕ (defined by the sides **14***b* of each adjacent pair of the teeth **14***a*) is substantially equal to the apex angle θ. This configuration reduces the force required for press fitting and guarantees the torsional torque transmitting capability between the FRP pipe **12** and the yokes **13**.

[0029] The torsional torque transmitting capability of the FRP pipe **12** and the press fitting force were examined by using the yokes **13** of varied apex angles θ and varied tooth height h of the serration **14**. The examination revealed that in the range of the apex angle θ between 45° and 75°, the press fitting force and the torsional torque transmitting capability are satisfactory. If the apex angle θ is less than 45°, the strength of the teeth **14***a* is not sufficient. If the apex angle θ is greater than 75°, a relatively great press fitting force is required.

[0030] The apex angle θ should be between 45° and 75°, preferably between 50° and 70°, more preferably between 55° and 65°.

[0031] When the apex angle θ is 45°, and the tooth height is 1.7 mm, the width W of the tooth distal end is slightly less than that in a case where the apex angle θ is 60°. When the apex angle θ is 75°, and the tooth height is 0.95 mm, the width W of the tooth distal end is slightly greater than that in a case where the apex angle θ is 60°.

[0032] This embodiment provides the following advantages.

[0033] (1) The propeller shaft **11** includes the FRP pipe **12** and the metal yokes **13** attached to the ends of the pipe **12**. Each yoke **13** has the serration **14** with the teeth **14***a*. The teeth **14***a* form the axially extending grooves **12***c* in the corresponding end of the pipe **12**. The apex angle θ of the teeth **14***a* is between 45° and 75°. Therefore, a force required when press fitting the serration **14** of each yoke **13** to an end of the FRP pipe **12** is reduced. Also, the torsional torque transmitting capability of the pipe **12** is improved.

[**0034**] (2) The apex angle θ of each tooth **14***a* in the serration **14** is between 45° and 75°. The connecting angle ϕ (defined by an adjacent pair of the teeth **14***a*) is substantially equal to the apex angle θ. Therefore, a force required when press fitting the serration **14** of each yoke **13** to an end of the FRP pipe **12** is reduced. Also, the torsional torque transmitting capability of the pipe **12** is improved.

[**0035**] (3) The radial dimension of the portion of each tooth **14***a* that digs into the FRP pipe **12** is equal to or less than one fifth of the tooth height h. Therefore, when press fitting the serration **14** of the yoke **13** into the FRP pipe **12**, the FRP pipe **12** does not receive excessive expanding force.

[**0036**] (4) The outer diameter of the serration **14** is between 70 mm and 75 mm, and the number of the teeth **14***a* is between 142 and 145. Thus, when pressing fitting the serration **14**, the FRP pipe **12** does not receive excessive expanding force.

[**0037**] (5) The serration **14** is formed such that the distance H between the intersection of adjacent lines Ls representing the sides **14***b* of the teeth **14***a* and the outer diameter line Ld of the serration **14** is between 0.9 mm and 1.8 mm. This configuration facilitates the machining of the serration **14**.

[**0038**] (6) The serration **14** is formed such that the distal tooth thickness T of the teeth **14***a* is equal to or less than 0.1 mm (In this embodiment, the distal tooth thickness T is 0.05 mm). This configuration requires less press fitting force and makes the digging amount appropriate.

[**0039**] (7) The serration **14** is formed such that the distal tooth thickness T of the teeth **14***a* is equal to or less than 0.1 mm and the width W of the proximal end of the teeth **14***a* is 1.5 mm. In this embodiment, the distal tooth thickness T is 0.05 mm. Therefore, a force required when press fitting the serration **14** of each yoke **13** to an end of the FRP pipe **12** is reduced. Also, the torsional torque transmitting capability of the pipe **12** is improved.

[**0040**] It should be apparent to those skilled in the art that the present invention may be embodied in many other specific forms without departing from the spirit or scope of the invention. Particularly, it should be understood that the invention may be embodied in the following forms.

[**0041**] The proximal ends of an adjacent pair of the teeth **14***a* need not be continuous. As shown in **FIG. 4**, the proximal ends may be separated by a predetermined distance. The connecting angle ϕ defined by the sides **14***b* of the adjacent pair of the teeth **14***a* is substantially the same as the apex angle θ. This modification has the same advantages as the case where the teeth **14***a* have a saw-tooth cross-section.

[**0042**] The sides **14***b* of each tooth **14***a* need not be linear as represented by lines Ls. Lines representing the sides **14***b* may be curved at the proximal end of the tooth **14***a*. In other words, the facing sides **14***b* of each adjacent pair of the teeth **14***a* are connected through a curved plane. In this case, the apex angle θ refers to the angle defined by the linear sections of lines Ls.

[**0043**] The sides **14***b* of the teeth **14***a* represented by lines Ls need not be linear. The entire sides **14***b* may be, for example, involute. If the ratio (h/W) of the tooth height h and the proximal width W is between 0.63 and 1.16, and the distal width is 0.05±0.02 mm, the force required for press fitting the serrations **14** to the ends of the pipe **12** is reduced, and the torsional torque transmitting capability is improved. If the sides **14***b* of each tooth **14***a* is flat and the ratio (h/W) is 1.16, the apex angle of each tooth **14***a* is approximately 45°. If the sides **14***b* of each tooth **14***a* are flat and the ratio (h/W) is 0.63, the apex angle is approximately 75°.

[**0044**] In **FIG. 4**, sections of the sides **14***b* of each tooth **14***a* at the proximal end may be arcuate. In other words,. the sides **14***b* of each tooth **14***a* are curved in the vicinity of the proximal end. The connecting angle ϕ need not be substantially the same as the apex angle θ.

[**0045**] In the illustrated embodiment, the yoke **13** includes the integrated engaging portion **13***a* and joint portion **13***b*. The serration **14** is formed on the engaging portion **13***a*. However, the engaging portion **13***a* and the joint portion **13***b* may be separately formed. The joint portion **13***b* may be welded or friction welded to the engaging portion **13***a* on which the serration **14** is machined. In this case, if a component used for conventional propeller shaft may be used as the joint portions **13***b*, the manufacturing cost is reduced.

[**0046**] In the modification where the yoke **13** is formed by welding the joint portion **13***b* to the engaging portion **13***a*, the joint portion **13***b* may be welded to the engaging portion **13***a* after the engaging portion **13***a* is press fitted in the FRP pipe **12**.

[**0047**] The radial dimension of the part of each tooth **14***a* that digs into the pipe **12** may be greater than one fifth of the tooth height. If the apex angle θ is approximately 45°, an amount of the digging portion that is greater than one fifth of the tooth height does not excessively increase the press fitting resistance and guarantees a sufficient torsional torque transmitting capability.

[**0048**] In the illustrated embodiment, the serration **14** is formed by machining a metal pipe on which the joint portion **13***b* is formed. However, the serration **14** may be formed through cold or hot forging.

[**0049**] Instead of the yokes **13**, metal shafts on which serration is formed may be press fitted in the FRP pipe **12**. In this case, the metal shafts function as the metal members.

[**0050**] The FRP pipe **12** need not be entirely cylindrical. However, the FRP pipe **12** may be a polygonal prism with the ends of circular cross-section.

[**0051**] The FRP pipe **12** may be manufactured through a method other than the filament winding method. For example, the FRP pipe **12** may be formed through sheet winding method. As long as the FRP pipe **12** has the required characteristics as a propeller shaft, the pipe **12** may be manufactured through any method. However, it is preferable that the pipe **12** be manufactured through filament winding.

[0052] The reinforcing fibers and the matrix resin of the FRP pipe **12** need not be carbon fibers and epoxy resin. For example, other types of fibers that have high elasticity and high strength such as aramide fiber and glass fiber may be used as the reinforcing fibers. Thermosetting resin such as unsaturated polyester, phenol resin, and polyimide resin may be used as the matrix resin.

[0053] The matrix resin of the FRP need not be thermosetting. For example, an ultraviolet curing resin or a thermoplastic resin may be used as the matrix resin.

[0054] Therefore, the present examples and embodiments are to be considered as illustrative and not restrictive and the invention is not to be limited to the details given herein, but may be modified within the scope and equivalence of the appended claims.

1. A fiber reinforced plastic propeller shaft comprising:

a fiber reinforced plastic pipe; and

a metal member attached to at least one end of the pipe, wherein the metal member is provided with a serration having a plurality of teeth having an apex angle, wherein, when the metal member is attached to the end of the pipe, each tooth forms on the inner surface of the pipe end a groove extending along the axial direction of the pipe, and wherein the apex angle of each tooth is between 45° and 75°.

2. The fiber reinforced plastic propeller shaft according to claim 1, wherein a connecting angle defined by facing sides of each adjacent pair of the teeth is substantially equal to the apex angle.

3. The fiber reinforced plastic propeller shaft according to claim 1, wherein a ratio of the height of each tooth to the width of the proximal end of each tooth is between 0.63 and 1.16, and wherein the width of the distal end of each tooth is 0.05±0.02 mm.

4. The fiber reinforced plastic propeller shaft according to claim 1, wherein the width of the distal end of each tooth is equal to or less than 0.1 mm.

5. The fiber reinforced plastic propeller shaft according to claim 1, wherein a section of each tooth that corresponds to one fifth of the height of the tooth digs into the inner surface of the pipe end.

6. The fiber reinforced plastic propeller shaft according to claim 1, wherein the outer diameter of the serration is between 70 mm and 75 mm, and wherein the number of the teeth is between 142 and 145.

7. The fiber reinforced plastic propeller shaft according to claim 1, wherein the metal member is a yoke.

8. The fiber reinforced plastic propeller shaft according to claim 1, wherein the apex angle of each tooth is between 50° and 70°.

9. The fiber reinforced plastic propeller shaft according to claim 1, wherein the apex angle of each tooth is between 55° and 65°.

10. The fiber reinforced plastic propeller shaft according to claim 1, wherein the width of the distal end of each tooth is 0.05±0.02 mm.

11. The fiber reinforced plastic propeller shaft according to claim 1, wherein the distal ends of each adjacent pair of the teeth are separated by a predetermined distance.

12. The fiber reinforced plastic propeller shaft according to claim 11, wherein the sides of each tooth are curved in the vicinity of the proximal end.

13. The fiber reinforced plastic propeller shaft according to claim 1, wherein a connecting angle defined by facing sides of each adjacent pair of the teeth is different from the apex angle.

14. The fiber reinforced plastic propeller shaft according to claim 1, wherein the distance between an imaginary circle containing the distal ends of the teeth and an intersection of straight lines each containing the side of one of any adjacent teeth is 0.9 to 1.8 mm.

15. The fiber reinforced plastic propeller shaft according to claim 1, wherein the height of each tooth is 0.9 to 1.8 mm.

16. The fiber reinforced plastic propeller shaft according to claim 1, wherein the facing sides of any adjacent teeth are connected through a curved plane.

17. The fiber reinforced plastic propeller shaft according to claim 1, wherein the metal member includes an engaging portion attached to an end of the pipe and a joint portion welded to the engaging portion.

18. A method for manufacturing a fiber reinforced plastic propeller shaft comprising:

preparing a fiber reinforced plastic pipe; and

attaching a metal member to an end of the pipe, wherein the metal member is provided with a serration having a plurality of teeth, wherein, when the metal member is attached to the end of the pipe, each tooth forms on the inner surface of the pipe end a groove extending along the axial direction of the pipe, and wherein the apex angle of each tooth is between 45° and 75°.

19. The method for manufacturing a fiber reinforced plastic propeller shaft according to claim 18, wherein the metal member includes an engaging portion and a joint portion, which are separately prepared in advance, and wherein step of attaching the metal member to the end of the pipe includes:

press fitting the engaging portion into the pipe; and

welding the joint portion to the engaging portion.

* * * * *